Sea Ice Climate Change Initiative: Phase 1

D3.4 Product User Guide (PUG)

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SIT v0.9

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Authorship

Role	Name	Signature
Written by:	Thomas Lavergne (SIC) Eero Rinne (SIT)	
Checked by:	Gary Timms	
Approved by:	Stein Sandven	
Authorised by:		

Distribution

Organisation	Names	Contact Details
ESA	Pascal Lecomte	Pascal.Lecomte@esa.int
NERSC	Stein Sandven, Natalia Ivanova	Stein.Sandven@nersc.no; natalia.ivanova@nersc.no
CGI (previously Logica)	Gary Timms, Ed Pechorro	gary.timms@cgi.com; ed.pechorro@cgi.com;
Met.no	Thomas Lavergne, Lars Anders Breivik, Steinar Eastwood	t.lavergne@met.no; larsab@met.no; s.eastwood@met.no
DMI	Leif Toudal Pedersen, Rasmus Tonboe	ltp@dmi.dk; rtt@dmi.dk
DTU	Roberto Saldo, René Forsberg, Henriette Skourup	rs@space.dtu.dk; rf@space.dtu.dk; hsk@space.dtu.dk
FMI	Marko Mäkynen, Eero Rinne, Ari Seina	marko.makynen@fmi.fi; eero.rinne@fmi.fi; Ari.Seina@fmi.fi
University of Hamburg	Stefan Kern	stefan.kern@zmaw.de;
University of Bremen	Georg Heygster	heygster@uni-bremen.de
University of Cambridge	Peter Wadhams, John Fletcher, Vera Djepa	pw11@cam.ac.uk; jfaf2@damtp.cam.ac.uk vd256@cam.ac.uk
MPI-M	Dirk Notz	dirk.notz@zmaw.de;
Ifremer	Fanny Ardhuin	Fanny.Ardhuin@ifremer.fr

Organisation	Names	Contact Details
AWI	Marcel Nicolaus, Stefan Hendricks	marcel.nicolaus@awi.de, stefan.hendricks@awi.de

Table of Contents

1 Introduction 7
1.1 Document Structure 7
1.2 Document Status 7
1.3 Reference Documents and Datasets 7
1.4 Acronyms and Abbreviations 8

2 Sea Ice Concentration (SIC) 10
2.1 Introduction 10
2.2 Scientific Description of the product 10
2.3 Technical description of the product 14

3 Sea Ice Thickness (SIT) 21
3.1 Introduction 21
3.2 Scientific Description of the product 21
3.3 Technical description of the product 23

List of Figures

Figure 2-1: Illustration of the mismatch between "True" SIC and most SIC retrieval based on Passive Microwave (PMW) algorithms as melted water grows at the surface of sea ice. 11

Figure 2-2: Maps of Sea Ice Concentration (left) and total uncertainty (right) from the SICCI SSM/I dataset, valid for 1995-11-15 15

Figure 2-3: Temporal coverage of the SSM/I (blue) and AMSRE (red) SIC datasets for CRDP of SICCI Phase 1 (v01.10) 18

Figure 3-1: Maps of sea ice thickness (top left), Freeboard (top right) and number of measurements per grid cell (bottom). All maps are for January 20 09. 23

List of Tables

Table 1-1: Reference Documents 8

Table 1-2: Acronyms 9

Table 2-1: Description of the status_flag values 17

Table 2-2: Instrument and platforms entering the two SIC datasets for version v01.11 of the CRDP, note that SSM/I F08 is listed for reference but does not enter the dataset. 17

Table 2-3: Definition for the NH and SH grids used for the Sea Ice Concentration dataset 19

Table 3-1: Description of status_flag values 25

1 Introduction

1.1 Document Structure

This document describes in detail the datasets for the Sea Ice ECV project produced in Phase 1 of ESA's Climate Change Initiative. The document includes the contributions for both the Sea Ice Thickness (SIT) and Sea Ice Concentration (SIC) aspects. Chapter 2 describes the Sea Ice Concentration product user guide and chapter 3 describes the Sea Ice Thickness product user guide.

1.2 Document Status

This is the 2nd issue of the PUG document.

1.3 Reference Documents and Datasets

ID	Reference Details
RD-1	Algorithm Theoretical Basis Document (ATBD), v2, Issue 1.1, Feb 2014
RD-2	Detailed Processing Model (DPM), v2, Issue 1.1, Feb 2014
RD-3	Product Validation and Intercomparison Report (PVIR), v1, *scheduled fall 2014*
RD-4	Product Validation and Algorithm Selection Report (PVASR), v1, Issue 1.0, June 2013
RD-5	Comprehensive Error Characterisation Report (CECR), v1, Issue 1.1, August 2013
RD-6	Warren, S. G., I. G. Rigor, N. Untersteiner, V. F. Radionov, N. N. Bryazgin, Y. I. Aleksandrov, and R. Colony (1999), Snow depth on Arctic sea ice, Journal of Climate, 12(6), 1814-1829.
RD-7	Kurtz, N. T., and S. L. Farrell (2011), Large-scale surveys of snow depth on Arctic sea ice from Operation IceBridge, Geophys Res Lett, 38.
RD-8	Guidelines for Data Producers - Climate Change Initiative Phase 1, Issue 4.2, May 2013
RD-9	Laxon, S. W., K. A. Giles, A. L. Ridout, D. J. Wingham, R. Willatt, R. Cullen, R. Kwok, A. Schweiger, J. Zhang, C. Haas, S. Hendricks, R. Krishfield, N. Kurtz, S. L. Farrell, and M. Davidson (2013), CryoSat-2 estimates of Arctic sea ice thickness and volume, *Geophys. Res. Lett.*, *40*, 1–6.
RD-10	GCOS : Systematic observation requirements for satellite-based data products for climate, 2011 Update
RD-11	EUMETSAT OSI SAF Global Reprocessed Sea Ice Concentration dataset v1.1, Product User Manual v1.3, October 2011, SAF/OSI/CDOP/met.no/TEC/MA/138

RD-12	Andersen, S., Tonboe, R., Kern, S., Schyberg, H., Improved retrieval of sea ice total concentration from spaceborne passive microwave observations using numerical weather prediction model fields: An intercomparison of nine algorithms, RSE, Vol 104, Iss 4, 2006, http://dx.doi.org/10.1016/j.rse.2006.05.013.
RD-13	Guidelines for Data Producers - Climate Change Initiative Phase 1, Issue 4.2, May 2013
RD-14	Brodzik, M.J.; Billingsley, B.; Haran, T.; Raup, B.; Savoie, M.H. EASE-Grid 2.0: Incremental but Significant Improvements for Earth-Gridded Data Sets. ISPRS Int. J. Geo-Inf. 2012, 1, 32-45.
RD-15	Fennig, K.; Andersson, A.; Schröder, M. (2013): Fundamental Climate Data Record of SSM/I Brightness Temperatures. Satellite Application Facility on Climate Monitoring. DOI:10.5676/EUM_SAF_CM/FCDR_SSMI/V001. http://dx.doi.org/10.5676/EUM_SAF_CM/FCDR_SSMI/V001
RD-16	Ashcroft, P. and F. J. Wentz. (2013): AMSR-E/Aqua L2A Global Swath Spatially-Resampled Brightness Temperatures. Version 2. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center. http://dx.doi.org/10.5067/AMSR-E/AE_L2A.002.
RD-17	Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M. A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A. C. M., van de Berg, L., Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A. J., Haimberger, L., Healy, S. B., Hersbach, H., Hólm, E. V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., McNally, A. P., Monge-Sanz, B. M., Morcrette, J.-J., Park, B.-K., Peubey, C., de Rosnay, P., Tavolato, C., Thépaut, J.-N. and Vitart, F. (2011), The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Q.J.R. Meteorol. Soc., 137: 553–597. doi: 10.1002/qj.828

Table 1-1: Reference Documents

1.4 Acronyms and Abbreviations

Acronym	Meaning
AMSR-E	Advanced Microwave Scanning Radiometer aboard EOS
AO	Announcement of Opportunity
ASCII	American Standard Code for Information Interchange
ASIRAS	Airborne Synthetic Aperture and Interferometric Radar Altimeter System
CM-SAF	Climate Monitoring Satellite Application Facility
CRDP	Climate Research Data Package
DMSP	Defence Meteorological Satellite Program
DWD	Deutscher Wetterdienst
ECV	Essential Climate Variable
Envisat	Environmental Satellite

Acronym	Meaning
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCDR	Fundamental Climate Data Record
FOC	Free of Charge
FOV	Field-of-View
FTP	File Transfer Protocol
GB	GigaByte
GCOM	Global Change Observation Mission
H	Horizontal polarization
H+V	Horizontal and vertical polarization
MB	MegaByte
MODIS	Moderate Resolution Imaging Spectroradiometer
n.a.	Not applicable
NetCDF	Network Common Data Format
NSIDC	National Snow and Ice Data Center
OIB	Operation Ice Bridge
OSI-SAF	Ocean and Sea Ice Satellite Application Facility
PI	Principal Investigator
PMW	Passive Microwave
POES	Polar Operational Environmental Satellite
PRF	Pulse Repetition Frequency
RADAR	Radio Detection and Ranging
SAR	Synthetic Aperture Radar
SIC	Sea Ice Concentration
SIRAL	SAR/Interferometric Radar Altimeter
SIT	Sea Ice Thickness
SMMR	Satellite Multichannel Microwave Radiometer
SSM/I	Special Sensor Microwave / Imager
SSM/IS	Special Sensor Microwave / Imager+Sounder
Tb	Brightness Temperature
TB	TeraByte
t.b.d.	To be determined
TM	Thematic Mapper
ULS	Upward Looking Sonar
URL	Uniform Resource Locator
V	Vertical polarization

Table 1-2: Acronyms

2 Sea Ice Concentration (SIC)

2.1 Introduction

This SIC part of the Product User Guide (PUG) provides the entry point to the European Space Agency Climate Change Initiative (ESA CCI) Sea Ice Concentration (SIC) dataset, both from a scientific and a technical point of view. Details of the scientific description of the processing chain and algorithms are however willingly kept out of this PUG, and the interested readers are rather directed to the Algorithm Theoretical Basis Document (RD-1), and Detailed Processing Model (RD-2). Validation and evaluation results are not contained in this PUG either, but in a Product Validation and Intercomparison Report (RD-3).

In short, the SICCI SIC dataset is:

- Daily gridded SIC fields based on Passive Microwave Radiometer measurements;
- Global maps (both Northern Hemisphere and Southern Hemisphere) with 25 km grid spacing;
- Both a SSM/I and a AMSR-E dataset, processed and delivered separately;
- Daily maps of total standard error (uncertainty) and quality control flags;
- Built upon the algorithms and processing software originally developed at the EUMETSAT OSI SAF for their SIC dataset (RD-11).

Contribution of the EUMETSAT OSI SAF to the production of this dataset is acknowledged. EUMETSAT OSI SAF provided access and allowed re-use of its SIC reprocessing software and data hosting facilities (RD-11). The reprocessing chain was further updated with the new algorithms and knowledge from the ESA CCI Sea Ice project.

2.2 Scientific Description of the product

This section gives a summary of the science features of the SIC dataset, and describes first the known limitations and caveats the potential users should be aware of before analysing the dataset. Note that this version of PUG is written before any extensive validation exercise of the dataset, and that the results described below are based on an algorithm selection exercise, described in a Product Validation and Algorithm Selection Algorithm (RD-4).

2.2.1 Known limitations and caveats

All the aspects listed in this section apply in large extent to the other existing Sea Ice Concentration datasets based on Passive Microwave Radiometer (PMR) measurements. Users of these datasets, including the SICCI one, should be fully aware of these so that not to bias their conclusions.

2.2.1.1 Summer melt-ponding

Virtually all Sea Ice Concentration algorithms based on the PMR channels around 19GHz, 37GHz, and 90GHz are very sensitive to melt-pond water on top of the ice. The depth of the emitting at these wavelengths indeed do not allow for distinguishing between ocean water (in leads) and melt water (in ponds). This is the main reason why PMR SIC datasets are underestimating sea ice concentration during summer.

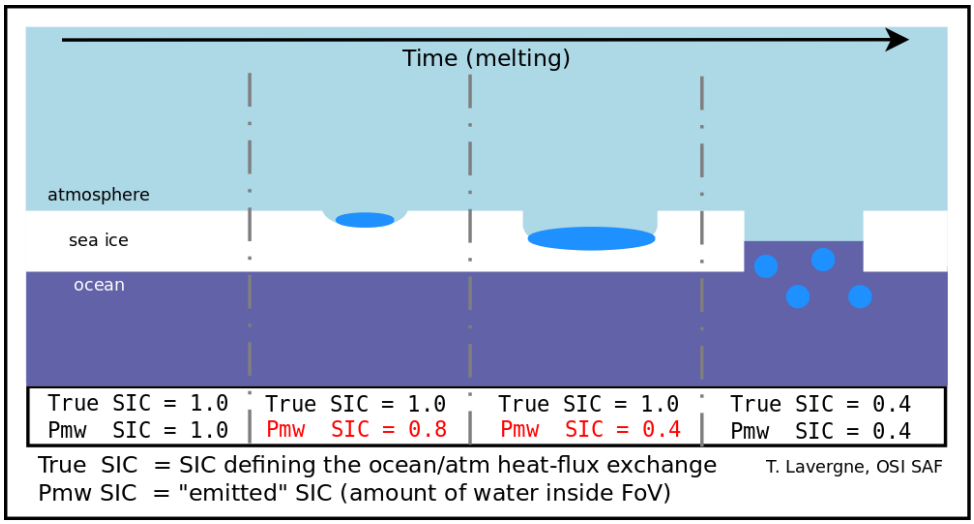
Time (melting)
atmosphere
sea ice
ocean
True SIC = 1.0
Pmw SIC = 1.0
True SIC = 1.0
Pmw SIC = 0.8
True SIC = 1.0
Pmw SIC = 0.4
True SIC = 0.4
Pmw SIC = 0.4
True SIC = SIC defining the ocean/atm heat-flux exchange
Pmw SIC = "emitted" SIC (amount of water inside FoV)
T. Lavergne, OSI SAF

Figure 2-1: Illustration of the mismatch between "True" SIC and most SIC retrieval based on Passive Microwave (PMW) algorithms as melted water grows at the surface of sea ice.

2.2.1.2 Thin sea-ice

Concentration of thin sea-ice (5-30cm) is underestimated by most of the "classic" PMR SIC algorithms, due to the radiometric contribution of water below the ice. A complete, 100% cover of thin sea-ice indeed does not act as a radiometric insulator for the PMR frequencies around 19 and 37 GHz that are the base for this SICCI dataset, and many others.

2.2.1.3 Interpolation of missing values

The SICCI SIC dataset aims at addressing needs from all users needing access to climate sea ice concentration data, from interested general public to climate modellers. Like for the OSISAF dataset, it was decided to provide interpolated sea ice concentration values in places where original input satellite data was missing, aiming at most complete daily maps. Both temporal and spatial interpolation is used. The locations were interpolation was used are clearly identified in the status_flag layer (see later section).

These interpolated sea ice concentration values should generally not be used for scientific applications, especially the values obtained from spatial interpolation.

2.2.1.4 The AMSR-E sea ice concentration time-series

The SICCI SIC dataset is composed of two CRDs, one from the SSM/I instrument, and one from the AMSR-E instrument. These time-series overlap partly.

Concerning the first version of the dataset (v01.11), the project team warns potential users that the AMSR-E SIC time-series is less mature than the SSM/I one, and that the former should be used with extra care, possibly after visual inspection or comparison to other data sources (such as the SSM/I time series during the overlap period).

Future versions of the SICCI dataset will bring the AMSR-E time-series to a similar maturity level as the SSM/I one.

2.2.1.5 Grid resolution

In [RD-10], the Global Climate Observing System Requirement (GCOS) requires horizontal resolution of 10-15 km, while a user survey conducted during the SICCI project confirmed need for SIC at resolutions below 10 km. This requirement is incompatible with the requirement to take advantage of the 30+ years long data record of PMW channels at 19 and 37 GHz (SMMR, SSM/I, SSMIS, etc...)

The present SICCI SIC products are delivered with a grid spacing of 25 km. The same grid spacing is used both for the SSM/I and the AMSR-E SIC dataset.

Since the footprint of the SSM/I channel at 19.35 GHz is roughly an ellipse of 45x70 km diameter, and since no attempt was made in the SICCI dataset to use "Resolution Enhancement" techniques, the true resolution of the SSM/I dataset is expected to be larger than the 25 km grid spacing.

The footprint of the AMSR-E 18.7 GHz channel being roughly an ellipse of 27x16 km diameter, the a grid spacing of 25 km is much closer to the true resolution of the SIC dataset.

2.2.1.6 Coastal regions

The radiometric signature of land is similar to sea ice at the wavelengths used for estimating the SIC. Because of the large foot-prints and the relatively high temperatures of land and ice compared to water, the land signature is "spilling" into the coastal zone open water and it will falsely look as intermediate concentration ice. This is sometimes called land-spill-over and it is partly removed in the processing using a combination of physical and statistical methods. However, this coastal correction procedure is not perfect, and a level of false sea-ice remains along some coastlines. This is less pronounced in the AMSR-E than in the SSM/I time-series thanks to AMSR-E's smaller foot-prints.

In addition to the land-spill-over effect, users of the SICCI datasets are made aware that SIC is only distributed in EASE2 25x25 km grid cells that have no fractional land-cover (conservative land mask). This is unlike what is done in other SIC datasets (like from OSISAF or NSIDC CDR) that allow some amount of sub-grid-cell land cover to co-exist with SIC values. This choice was made in SICCI because the correction from land-spill-over effect is not performing well enough, and the SIC values distributed in grid-cells

with fractional land-cover would have been mostly un-reliable. This might lead to systematic low-bias of Sea Ice Extent or Sea Ice Area time-series when computed from the SICCI datasets, on hemispheric scales.

Both the land-spill-over correction, and the fractional land cover aspects will be further investigated in later release of the SIC dataset.

2.2.2 Description of the processing chain and algorithms

In this section, we highlight the features of the SICCI processing chain and algorithm that make this SIC dataset different from others. More details can be found in RD-1 and RD-2.

2.2.2.1 Input data

The SIC datasets produced in the SICCI project ingest the following input data:

- The EUMETSAT CMSAF SSM/I Tb FCDR V001 (RD-15);
- The NSIDC/Wentz AMSR-E Tb FCDR V002 (RD-16);
- The ERA-Interim daily atmosphere analysis fields (RD-17).

Contribution of these scientific teams and data providers to the SICCI SIC dataset is acknowledged.

2.2.2.2 Sea Ice Concentration algorithm

The sea ice concentration algorithm used in the SICCI dataset is based on three PMR channels, near 19 GHz (Vertical polarization) and 37 GHz (both Vertical and Horizontal polarizations). Like for the OSI SAF SIC dataset (RD-11), the SICCI algorithm intercomparison exercise (RD-4) concluded that these channels are best combined in a mixture of Comiso Bootstrap Frequency mode algorithm (CF), and Bristol algorithm (BR). CF is given more weights at low concentrations range, while BR estimates dominate at high concentrations range. The way this merging is done in SICCI was revised with respect to the OSI SAF.

2.2.2.3 Dynamic tuning of tie-points

One of the key features of the SICCI dataset is the dynamical adjustment of the algorithm Tie-Points. For SIC PMR algorithms, the tie-points are typical radiometric signature of 0% ice (Open Water TP) and 100% ice (Closed Ice TP). In most other PMR datasets, these tie-points are either fixed or varying with seasons in a prescribed way.

For the SICCI SIC dataset, the Tie-Points to the algorithm are adapted to the sensor data and vary every day as a running average over a [-7 days; +7 days] window (a running average over a [-15 days; +15 days] window was used in the OSISAF data record RD-11). In addition, the Open Water Tie-Point is selected in a buffer region at the outer limit of a monthly varying climatological mask, to ensure that these Open Water signatures are representative for the typical weather conditions prevailing in the vicinity of the ice edge (see RD-1).

Being derived separately for each sensor and platform, dynamic Tie-Points also ensure that residual inter-satellite calibration offsets have minimal impact on the final ECV.

2.2.2.4 Atmospheric correction of Brightness Temperatures

Following the approach of the OSI SAF dataset, the SICCI processing chain includes correction of the brightness temperatures from atmospheric and surface effects using a Radiative Transfer Model (RTM). Fields of 10m wind speed, total columnar water vapour, and temperature at 2m, from the ECMWF ERA-Interim reanalysis are used in this process.

The atmospheric correction scheme from Andersen et al. 2006 [RD-12] is implemented, that includes an iteration to first correct the dynamic Tie-Points, and then use these corrected Tie-Points along with the corrected brightness temperatures (see [RD-2]).

2.2.2.5 Per-pixel uncertainty estimates

The SICCI SIC dataset comes with uncertainty estimates for every grid cell with ice concentration value. All uncertainties are intended as one standard deviation around the provided sea ice concentration value (acting as the mean of the distribution).

2.3 Technical description of the product

In this section, the SIC product files are described in terms of content, file name, data format, grid, among others.

2.3.1 Examples

To support the reading of the technical specifications, we start this section by providing some visualization examples of maps extracted from the product files. These are shown on the following page.

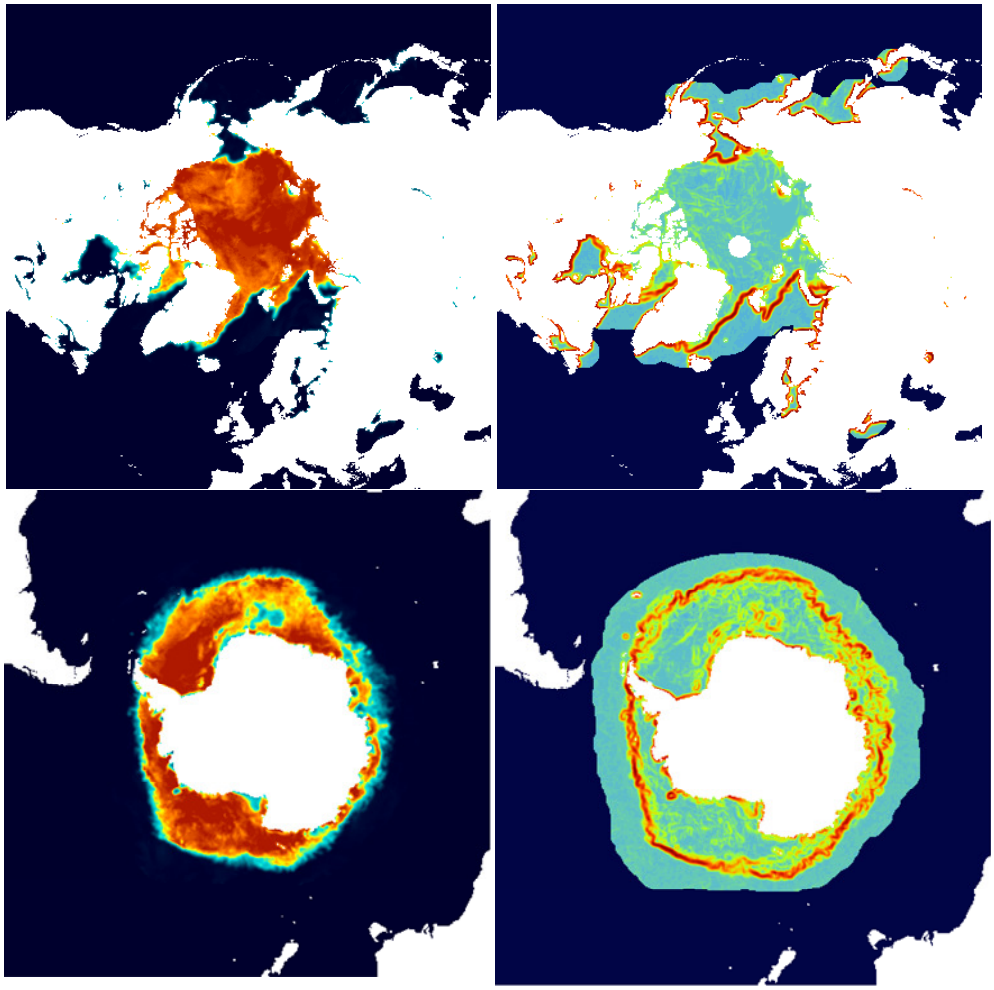

Figure 2-2: Maps of Sea Ice Concentration (left) and total uncertainty (right) from the SICCI SSM/I dataset, valid for 1995-11-15

2.3.2 Content of product files

The distributed product files are so called "Level 4" files that are daily gridded maps of sea ice concentration and their uncertainties. To achieve global coverage, two product files are available per day, one covering the Northern Hemisphere sea ice, and the other the Southern Hemisphere. Each file contains:

- a time information encoding date and time for the daily product (average from 00 to 23:59 UTC);
- latitude and longitude for each grid point;
- a map of analysed, daily averaged sea ice concentration;
- a map of processing (aka status) flags;
- three maps of uncertainties as standard deviations (total, algorithm, and smear uncertainties);

- a map of values retrieved outside the physical range [0%-100%];
- a number of metadata information, both pertaining to the given date, and to the whole time-series.

Note that all the variables encoding sea ice concentration (both the ice concentration variables themselves, and their uncertainties) have unit "%", that is they are ranging from 0 to 100%.

2.3.2.1 The sea ice concentration variables

There are two sea ice concentration variables in the product file, one given the "physical" ice concentration, bounded in [0-100%] range (ice_conc), the second that only provides the grid cell values retrieved out of bounds by the algorithm (ice_conc_off_range).

These non-physical values are distributed to the special interested users that may benefit from accessing un-biased distributions of the ice concentration distribution, especially for use with Data Assimilation.

Note that the main variable, ice_conc, can contain interpolated ice concentration values, that can be detected using the status flags (see below) and should generally be used with great care for any scientific purpose (see section 2.2.1.3).

3.2.2 The uncertainty variables

There are three uncertainty variables in the product files: the total uncertainty (total_standard_error) and its two components (smearing_standard_error and algorithm_standard_error). The total uncertainty is the sum of the smearing and algorithm uncertainties (as variances).

2.3.2.2 The status flags

The status_flag can take 10 values, listed in Table 2-1.

Value	Meaning	Comment
0	nominal	SIC values delivered with the nominal uncertainty.
1	high_t2m	Warning that ERA-Interim T_{2m} is higher than 10 degrees Celsius, this might be false ice.
2	lake_ice	Sea-water hemispheric coefficients was applied over a lake, the quality is unknown.
10	coast_corr	The SIC value was corrected because in the direct vicinity of land. Vicinity of land usually leads to overestimation of the SIC values, even after coastal correction is applied. See 2.2.1.6.
11	max_ice_climo	The region is flagged as having never seen sea ice, and SIC is accordingly set to 0 (the total uncertainty as well).

12	low_latitude	The region is "equatorward" of +/- 35 deg latitude and SIC is set to 0 (the total uncertainty as well).
13	interp_spatial	The SIC value was obtained from spatial interpolation, caution!
14	interp_temporal	The SIC value was obtained from temporal interpolation, caution!
100	land	No SIC data is provided because there is land in the grid cell (either full or fractional cover). The `_FillValue` is used. See 2.2.1.6.
101	missing	No SIC data is provided because missing satellite input data (even after interpolation). The `_FillValue` is used.

Table 2-1: Description of the status_flag values

2.3.3 Temporal coverage

The Sea Ice Concentration dataset is made of two time-series, one merging all SSM/I instruments aboard DMSP F10, F11, F13, F14, and F15, the second covering AMSR-E instrument. Table 2-2 and Figure 2-3 summarize the temporal coverage of the SIC datasets.

SIC dataset	Instrument and platform	First Date	Last Date
SSM/I	*SSM/I F08*	*9 July 1987*	*8 December 1991*
	SSM/I F10	7 January 1991	14 November 1997
	SSM/I F11	1 January 1992	31 December 1999
	SSM/I F13	3 May 1995	31 December 2008
	SSM/I F14	7 May 1997	23 August 2008
	SSM/I F15	28 February 2000	31 July 2006
AMSR-E	AMSR-E Aqua	19 June 2002	3 October 2011

Table 2-2: Instrument and platforms entering the two SIC datasets for version v01.11 of the CRDP, note that SSM/I F08 is listed for reference but does not enter the dataset.

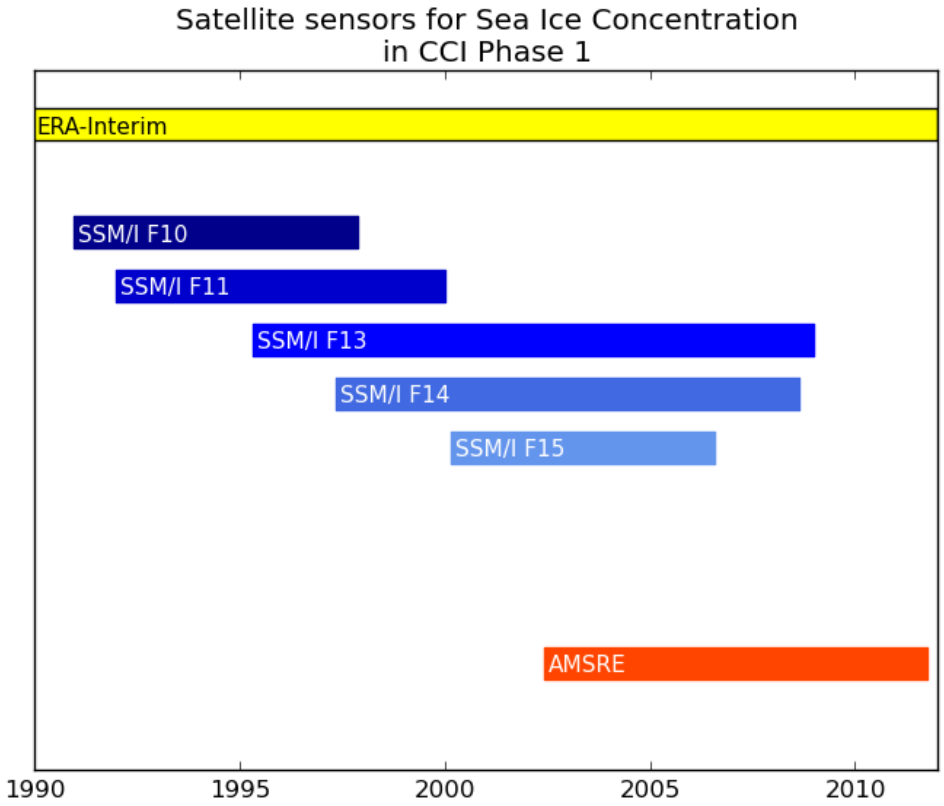

Figure 2-3: Temporal coverage of the SSM/I (blue) and AMSRE (red) SIC datasets for CRDP of SICCI Phase 1 (v01.10)

Note that in v01.10 and subsequent CCI Phase 1 versions of the dataset, SSM/I F08 was not used due to occurrence of bad scans in the CM-150 SSM/I Tb FCDR (Version 1, revision 1).This was later corrected in CM-SAF FCDR. Note also that the CM-SAF SSM/I Tb FCDR has last date on 31 December 2008, and although SSM/I F13 continues operations after this date, the current SIC SSM/I dataset stops at that date.

2.3.4 Product grid and geographic projection

The SSM/I and AMSR-E SIC datasets are delivered on a set of two polar EASE2 grids, with a grid spacing of 25 km. The EASE2 projection is defined in [RD-14]. The two grids are defined in Table 2-3 (below). See also Figure 2-2.

Grid ID	PROJ4 string	X,Y boundaries and spacing [km]	Latitude-Longitude bounding box [deg]
NH25kmEASE2	+proj=laea +lon_0=0 +datum=WGS84 +ellps=WGS84 +lat_0=+90.0	X: -5387.5, -5362.5,..., +5387.5 Y: +5387.5, +5362.5,..., -5387.5	:geospatial_lat_min = 16.62393f ; :geospatial_lat_max = 90.f ; :geospatial_lon_min = -180.f ; :geospatial_lon_max = 180.f ;
SH25kmEASE2	+proj=laea +lon_0=0 +datum=WGS84 +ellps=WGS84 +lat_0=-90.0	Same as above	:geospatial_lat_min = -90.f ; :geospatial_lat_max = -16.62393.f ; :geospatial_lon_min = -180.f ; :geospatial_lon_max = 180.f ;

Table 2-3: Definition for the NH and SH grids used for the Sea Ice Concentration dataset

2.3.5 Convention for file names

The Sea Ice Concentration dataset follows form 2 from [RD-13], that is:

ESACCI-SEAICE-L4-SICONC-<INSTR>-<AREA>25kmEASE2-<YYYYMMDD>-fv<VER>.nc

where the values for each <FIELD> can be:

- <INSTR> : SSMI or AMSR
- <AREA> : NH or SH
- <YYYYMMDD> : date string
- <VER> : product version (<XX.YY>)

2.3.6 File format

Following [RD-13], the Sea Ice Concentration datasets are netCDF files that follow the Climate and Forecast (CF) convention (http://cfconventions.org).

The netCDF files are of type "netCDF-4 classic model" with internal compression (deflate level 9). Most variables are stored as int16 (short int), with associated scale_factor in order to reduce requirements on disk space. The status_flag dataset is encoded as byte.

2.3.7 Access to data

The SIC data can be accessed via a variety of sources:

- Via FTP on ftp://osisaf.met.no/.sicci/
- Via the Arctic Data Portal on http://arcticdata.met.no/
- Via the Integrated Climate Data Portal (ICDC) on http://icdc.zmaw.de/esa-cci_sea-ice-ecv0.html?&L=1

2.3.8 Dataset version history

2.3.8.1 V01.11 (15.04.2014)

Quality checked version of CRDP (SSM/I and AMSR-E). v01.11 has exactly the same scientific content as v01.10 but some dates were removed after manual and semi-automatic inspection of the time series. v01.11 pertains of SSM/I (01.01.1992 -> 31.12.2008) and AMSR-E (19.06.2002 -> 03.10.2011).

2.3.8.2 v01.10 (11.03.2014)

Release of CRDP (only SSM/I first) v01.10 pertains of SSM/I (07.01.1991 -> 31.12.2008).

2.3.8.3 Earlier versions

Several earlier versions existed (v00.10, v00.20, v01.00) for internal tests and validation.

3 Sea Ice Thickness (SIT)

3.1 Introduction

This SIT part of the Product User Guide (PUG) provides an entry point to the European Space Agency Climate Change Initiative (ESA CCI) Sea Ice Thickness (SIT) dataset, both from a scientific and a technical point of view. Details of the scientific description of the processing chain and algorithms are however deliberately kept out of this PUG, and the interested readers are rather directed to the Algorithm Theoretical Basis Document [RD-1], and Detailed Processing Model [RD-2]. Validation and evaluation results are not contained in this PUG either, but in a Product Validation and Intercomparison Report [RD-3].

In short, the SICCI SIT dataset is:

- Monthly gridded SIT and sea ice freeboard (FB) fields with 100 km grid spacing for the Arctic for the freezing season (October-March) based on radar altimeter measurements
- Maps of uncertainties and quality control flags

3.2 Scientific Description of the product

This section gives a summary of the science features of the SIT dataset, and describes first the known limitations and caveats the potential users should be aware of before analysing the dataset. Note that this version of PUG is written before any extensive validation exercise of the dataset, and that the results described below stem from the Comprehensive Error Characterisation Report (CECR) [RD-5] which in turn is based predominantly on past research and experience.

3.2.1 Known limitations and caveats

Subsections below describe the main limitations and caveats of SIT estimation from radar altimetry. These should be taken into account by all users of the product. Users wanting more detailed information on limitations and uncertainties of or products should refer to the CECR and PVASR documents [RD-5 and RD-4].

3.2.1.1 Speckle

All radar echoes exhibit a form of signal distortion known as ‘speckle’. As the speckle de-correlates between consecutive echoes, summing over n echoes reduces the noise due to speckle. Therefore, for gridded ice thickness products, the errors depend on the number of observations in a particular grid cell. Speckle is the main reason why the number of observations per grid cell is included in the SIT product. The effect of speckle in a single measurement is considerable when compared to expected freeboard. Thus freeboard and thickness values in grid cells, with only a few measurements, should be used with caution.

3.2.1.2 Radar penetration

We assume that during cold winter months the dominating scattering surface for the radar is the snow/ice interface. However, one of the outcomes of our Round Robin Exercise was that this is not always the case. Thus the user is reminded that the freeboard given in the SICCI SIT product files is the radar freeboard which we assume to be the elevation of upper surface of ice measured from local sea level. Nevertheless there is ongoing scientific discussion on how accurate this assumption is. If the dominating scattering surface lies somewhere within the snowpack, sea ice thickness retrieval using the radar freeboard with the incorrect assumption will result into too large thickness values.

3.2.1.3 Errors associated with the conversation of freeboard to thickness

The freeboard is converted into thickness by assuming the ice to be in hydrostatic equilibrium. This requires estimates of snow thickness as well as snow, ice and water densities. Uncertainty in all of these will contribute to the uncertainty of the thickness estimate.

Snow depth and density is estimated using the monthly snow depth climatology by Warren et al. [RD-6], which is based on measurements performed between 1954 and 1991 over multiyear ice. The use of a climatology means that interannual and local spatial variability are not represented – as is also shown in the PVASR [RD-4]. Furthermore the recent decline of multiyear ice has been shown to change the snow thicknesses in the Arctic. The snow depth on first year ice is approximately 50% of that given by the Warren et al. climatology [RD-7]. The geographical area from which snow depth measurements are used in the Warren et al. climatology limits the region for which the freeboard to thickness conversion can be applied. Snow depths from outside this geographical area such as the Hudson Bay are based on extrapolation and shall not be used for the conversion therefore.

Potential changes in the seasonal cycle of the snow density as provided by the Warren et al. climatology in comparison to conditions today might exist but have not yet been investigated. We recommend to keep using the seasonally varying snow density as provided by the Warren et al. climatology.

The sea ice density is estimated to be constant over the whole Arctic regardless of the ice type. There are direct measurements available that show density of ice to decrease with age. However introducing ice type dependent ice density did not improve the fit between validation data and radar altimeter derived ice thicknesses during the round robin exercise. This does not preclude, however, that usage of an ice-type dependent ice density will not improve freeboard to thickness conversion – as has been demonstrated, e.g. by Laxon et al. [RD-9]. The set of validation data available for the RRE did not yet allow making a quantitative statement with regard to the choice of the correct ice density.

If users have access to alternative sources of snow information and/or ice density, they are encouraged to calculate their own thicknesses from SICCI freeboard estimates.

3.2.1.4 Sampling error

The pulse limited footprint of a traditional radar altimeter is several kilometres wide. In consequence the radar altimeter may not sample the smallest floes and if the statistics of the sampled ice are different to the total ice cover then this will result in an error in the retrieved ice thickness.

3.2.2 Description of the processing chain and algorithm

For detailed description of algorithm, user should refer the ATBDv2 [RD-1]. The algorithm is based on distinguishing altimeter echoes from leads and ice floes, retracking elevations for both surface types, interpolating local sea level height from lead elevations and subtracting it from floe elevations. This results into freeboard. The thickness is then calculated from the freeboard with independent estimates of snow loading and ice density.

3.3 Technical description of the product

3.3.1 Examples

To ease and support the reading of the technical specifications, we start this section by providing some visualization of maps extracted from the product files. Note that there is a quality-flag layer in addition.

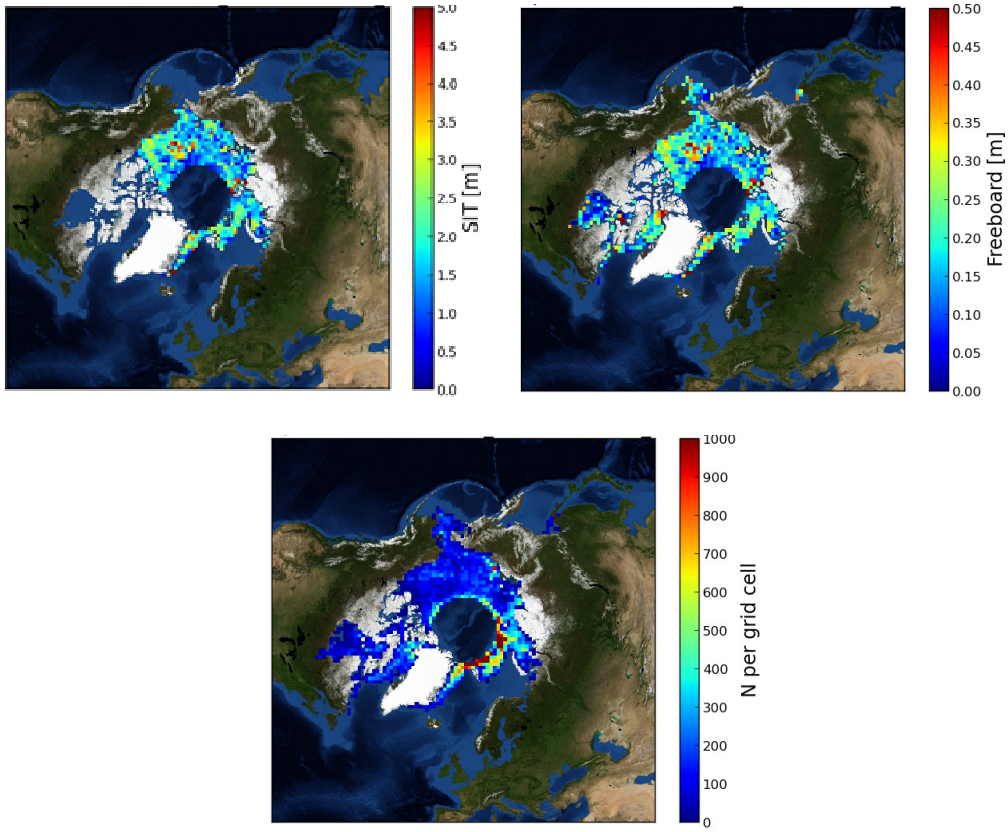

Figure 3-1: Maps of sea ice thickness (top left), Freeboard (top right) and number of measurements per grid cell (bottom). All maps are for January 20 09.

3.3.2 Content of product files

The distributed product files are so called "Level 3C" files. These contain monthly gridded maps of sea ice thickness and freeboard with some additional layers to assist the user in the interpretation of these maps.

3.3.2.1 The sea ice thickness and freeboard variables

There are variables for sea ice thickness and freeboard (sea_ice_thickness and sea_ice_freeboard, respectively).

Note that the given values are mean values of successful altimeter measurements inside the grid cell. They do not consider the fraction of open water – if only one 3 m floe is measured in a 100 km x 100 km, it will result into the sea_ice_thickness of 3 m.

3.3.2.2 Number of measurements per grid cell

The number of measurements averaged to retrieve a freeboard value is vital to know when estimating effect of radar speckle in freeboard retrieval. Thus this number is provided as a variable. Low number of measurements will result in higher uncertainties and cells with only few measurements sho uld be used with caution.

3.3.2.3 The uncertainty variables

There are uncertainty fields in the product files, but currently no uncertainty estimates are given. This is because a decision was made that the uncertainty estimates for freeboard and in consequence sea ice thickness will stem from experimental validation of the product still to be carried out during 2014. When the uncertainties have been set, a new product version will be published. For now, all uncertainty fields have been set to _Fillvalue.

3.3.2.4 The status flags

The status_flag can take 5 values, listed in Table 3-1 below:

Value	Meaning	Comment
1	nominal	SIT and FB values given
2	FB but no SIT	FB given but no SIT. This is due to no valid snow estimate available ("point outside the central Arctic and thus Warren et al. climatology is potentially not valid")
3	FB retrieval unsuccessful	Ocean, but no FB measurements available. Most likely open water.
100	land	No SIT data is provided because there is land in the grid cell (either full or fractional cover). The `_FillValue` is used.

101	polehole	No SIT data is provided because missing satellite input data due to the pole hole (lat > 82.5N). The `_FillValue` is used.

Table 3-1: Description of status_flag values

3.3.3 Temporal coverage

The dataset covers the Arctic winter months (October, November, December, January, February and March) of the Envisat operational period. This results into a winter dataset from October 2002 to March 2012.

3.3.4 Product grid and geographic projection

Both the SIT dataset is delivered on a polar EASE2 grid, with a grid spacing of 100 km. The EASE2 projection is defined in [RD-10]. The grid is defined by:

Grid ID	PROJ4 string	X,Y boundaries and spacing [m]	Latitude-Longitude bounding box [deg]
`NH100kmEASE2`	+proj=laea +lon_0=0 +datum=WGS84 +ellps=WGS84 +lat_0=+90.0	X: -5350000, -5250000 … 5350000 Y: 5350000, 5250000 … -5350000	:geospatial_lat_min = 17.22003 :geospatial_lat_max = 90.0 :geospatial_lon_min = -180.0, :geospatial_lon_max = 180.0 ;

3.3.5 Convention for file names

The Sea Ice Thickness dataset file naming follows the form:

<YYYYMM>-ESACCI-L3C_SEAICE-SIT-<INSTR>-fv<VER>.nc

where the values for each <FIELD> can be:

- <INSTR> : RA2_ENVISAT
- <YYYYMMDD> : date string
- <VER> : product version (<X.Y>)

3.3.6 File format

Following [RD-8], the Sea Ice Concentration datasets are netCDF files that follow the Climate and Forecast (CF) convention (*http://cfconventions.org*).

3.3.7 Access to data

The SIT data can be accessed via the Integrated Climate Data Portal (ICDC) at location: *http://icdc.zmaw.de/esa-cci_sea-ice-ecv0.html?&L=1*

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